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Reminiscence of PWI studies performed under international co-operations and suggestions for future works.
国際協力によるPWI研究

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Plasma materials interactions (PMI) with DT fuels in a reactor are so hard to realize and hence no one has ever experienced. PMI studies require interdisciplinal R&D, i.e., physics, chemistry and engineering to handle extremely low temperature materials (Ice pellet of hydrogen) to high temperature (burning plasma) including radioactive materials (tritium and neutron activated materials) and the PMI phenomena are synergistic. Based on the author's experience on international cooperational research, necessary future international cooperation is suggested.

1. General

In recent days, "globalization" is often reiterated, and even in scientific community international cooperation is in some sense forced to apply fund and/or budget.

TEXTOR cooperation under IEA agreement among EU, Japan, Canada and US was initiated by prof. A. Miyhara at 1987. Since then lots of brilliant achievements have been produced particularly in a field of plasma materials interactions (PMI), because TEXTOR has been dedicated to PMI studies.

The author has joined the program and initiated a new research program of "high Z limiter test in TEXTOR", since then more than 10 Japanese researchers have joined and more than 100 papers have been published. The program has been extended to other subjects like production, transport and deposition of impurities, tritium retention and others. Furthermore, cooperation with JET and ASDEX is now ongoing. Happily the program can be categorized as one of the most successful international cooperation program.

The PMI study considering tritium usage is now one of the key issues to establish burning plasma. And even JET is focusing this issue modifying PFM from full carbon to ITER like wall, i.e. Be and W. As described later, test beds to use W as PFM is quite limited, and we need strong cooperation or involvement in JET experiments.

In this presentation, based on the author's experiences of international cooperation, necessary future international cooperation is suggested.

2. Problems remaining or requested urgent solution in PMI filed.

All problems are originated from divertor and handling tritium. How to handle or what material can tolerate steady state heat load of 10-20 MW/m^2 and transient heat load of a few MJ given by giant ELM and/or disruption?

Because of safety concerns of tritium retention, EU seems exclude carbon and select W. However, utilization of brittle materials below their DBTT (ductile brittle transition temperature), (ITER is just the case) can easily results materials fault due to their brittlement or easy crack propagation. Fig.1 is a photograph of cracked W. The crack occurred unintentional use of the W limiter below its DBTT, (Usually the limiter was preheated) in the TEXTOR. The result itself was not a good example of the cooperation. Nevertheless, such kind of new finding encourages and brought bitter smile. The results irrespective of whether it is successful or not, are important.

Before starting the W limiter experiments in TEXTOR, most of plasma physicists were against to use W as PFM. In Japan, no tokamaks allowed us to use high Z materials in their PFM. After the long and hard discussion with scientists in TEXTOR,

Fig. 1 Brocken W test limiter owing to unintentional usage below DBTT

they allowed us to start the Mo limiter test.

From the results, we noticed that plasma can tolerate high Z PFM but without additional heating like NBI, high Z impurities accumulate in plasma center to result in minor or major disruption [1]. The plasma behavior was quite similar for Mo and W, even for Kr and Xe gas puffed in.

Once people noticed new results, irrespective of successful or not, they are willing to precede experiments further and hot discussion on new events encourages to realize more severe experiments to understand the new results.

Followed by the high Z limiter experiments in TEXTOR, ASDEX changed its carbon PFM to full W. Now even “full-W divertor from day first in ITER” is proposed. But this seems dangerous. Referring the cracking damage in fig.1, one should note how dangerous of W usage below its DBTT.

TEXTOR cooperation was really useful for both of Japanese side in that we could use only one tokamak in the world which has been dedicated to PMI studies.

Not only the ideas, but also a new technique can be brought into an international cooperation. One good example is tritium measurements. A tritium profile on TFTR bumper limiter, which was done just by a voluntary base without any official procedure, but scientists from our side and PPPL agreed to make experiments and got excellent results were obtained.

3. Necessary works in future

3-1.W relating works

Problems arise from heat load and He pumping in divertor and tritium usage. In particular, understanding of W behavior in ITER divertor like condition is urgent. Unfortunately, JT-60U is closed and JET will provide opportunity to study W, though its heat load is still far low. ASDEX could be also the test bed, but in order to avoid W accumulation in the plasma center, their operational plasma conditions are rather limited and studies on intentional disruptions or ELM have not been done yet. To study W accumulation, high temperature plasma is necessary. Referring O accumulation, low temperature plasma has been hard to tolerate the radiation of oxygen, so as W radiation. Nevertheless high Z accumulation must be avoided. We have to wait experiments with “ITER like wall” in JET, now just started. Hopefully, new international cooperation with JET will be done.

3-2. Carbon related works

Because of sever radiation damage and large tritium retention, utilization of carbon as PFM in ITER and a reactor seems to be minimized or avoided. As mentioned above, however, concerns on materials properties of W do not allow relying on W as PFM. We should not forget low activation and tolerance of high heat load of C. Furthermore, possible in-situ repairing by carbon deposition and low hydrogen uptake at higher temperature attracts C. Hence R& D for C must be continued. The author personally very much concerns manufacturers of carbon, in particular, CFC, leaving to other large markets. The R&D of PFM must be done internationally. Domestic market is too small to encourage them.

3-3. Tritium in burning plasma

Burning efficiency in a fusion fuel cycle is, unfortunately, very poor; i.e. only a few % or less of input tritium burns and the majority must be recovered to recycle. In addition, large in-vessel fuel retention rate would result in the huge in-vessel tritium inventory, which is hard to remove and recover. Since exhausted fuel from the vessel includes all hydrogen isotopes (H, D, and T), He and other impurities like water and hydrocarbons, the hydrogen isotopes must be refined and isotopicaly separated with each other to be recycled as fuels.

One should note that the number of tritium handling facilities is decreasing. And only one or two laboratories can be handle massive amount of tritium. Our experience of handling the massive amount of tritium in large volume like tokamak is very poor, and multi-step contaminations really concerns us.

4. Conclusion

PMI with DT fuels in a reactor are so hard to realize and hence no one has ever experienced. PMI studies require interdisciplinal R&D, i.e., physics, chemistry and engineering to handle extremely low temperature materials (Ice pellet of hydrogen) to high temperature (burning plasma) including radioactive materials (tritium and neutron activated materials) and the PMI phenomena are synergistic.

There are numbers of apparatus including tokamaks, high heat load test machines, tritium plasma source etc. Although each apparatus can simulate certain phenomena expected in ITER divertor, no one can realize conditions appearing in ITER divertor simultaneously. In addition, no one laboratory or institute has all apparatus, and these are widely distributed.

The conclusion is quite simple. PMI studies do require international cooperation considering real PMI phenomena in a reactor.